SUMMARY

PHASE II STUDY OF HEAD-END STEERING FOR A SIMPLIFIED MANNED SPACE VEHICLE

MARCH 1966
DOUGLAS REPORT SM-53104

MISSILE & SPACE SYSTEMS DIVISION
DOUGLAS AIRCRAFT COMPANY, INC.
SANTA MONICA/CALIFORNIA

DOUGLAS

SUMMARY

PHASE II STUDY OF HEAD-END STEERING FOR A SIMPLIFIED MANNED SPACE VEHICLE

MARCH 1966
DOUGLAS REPORT M-53104

PREPARED FOR NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, LANGLEY RESEARCH CENTER, LANGLEY FIELD, VIRGINIA, CONTRACT NO. NAS1-5451

PREPARED BY
G.M. FULLER
PROJECT ENGINEER
LIFTING BODY VEHICLES

APPROVED BY
S.L. HISLOP
PROGRAM MANAGER
LIFTING BODY VEHICLES

APPROVED BY
R.J. GUNKEL
DIRECTOR
ADVANCE MANNED SPACECRAFT SYSTEMS
ADVANCE SYSTEMS AND TECHNOLOGY

DOUGLAS MISSILE & SPACE SYSTEMS DIVISION

PREFACE

This document is submitted to the National Aeronautics and Space Administration's Langley Research Center in response to Contract No. NAS 1-5451. It presents a summary of a report by the Douglas Aircraft Company, Inc., on the Phase II study of head-end steering for a simplified manned vehicle. The text of the report may be found in Douglas Report SM-51872.

CONTENTS

SUMMARY

The Phase II study of head-end steering for a simplified manned space vehicle was conducted by the Douglas Aircraft Company, Inc., for the National Aeronautics and Space Administration's Langley Research Center (NASA-LRC), under Contract NAS 1-5451. This study was motivated by a continuing NASA interest in the reduction of costs and system complexity for manned space operations. The study period extended from July 1965 to February 1966.

The two objectives of the Phase I study, which was completed in December 1964, were (1) to define a system concept which stressed simplicity in the expendable components and reusability in those systems that were recovered and (2) to perform a first-order evaluation of technical and economic feasibility for the system concept.

The Phase I study resulted in a manned space vehicle concept which had as a baseline the logistics support of a space station in low Earth orbit at an altitude of 300 nmi. The spacecraft configuration featured (1) an HL-10 lifting body with the capability of transporting up to 11 passengers and 2 crewmen; (2) a booster steering and in-orbit maneuvering propulsion system located in the HL-10; (3) design maximum cargo provisions for up to 5,000 lb in the HL-10 and up to 18,750 lb in the cargo-module adapter; and (4) a 3-stage solid-propellant booster system. The 3-stage booster consisted of 260-in. diam 1st and 2nd stages and a 156-in. diam 3rd stage. Steering thrust vector control was accomplished entirely from the HL-10 spacecraft.

The results of the Phase I study indicated that the head-end steering system concept possessed the following attributes:

1. Technical feasibility.
2. The potential for a sizable reduction of operations costs.
3. Significant reduction in launch pad occupancy time.
4. Faster response times.

Several key questions were identified at the end of the Phase I Study:

1. How much system optimization is possible?
2. What is the relative reliability inherent in the system concept?
3. What part of the total cost reduction potential could be attributed to the following:
   A. Head-end steering?
   B. Launch vehicle propulsion?
   C. Spacecraft configuration?

Therefore, the objectives undertaken in the Phase II study were (1) to refine and optimize the system concept developed in the Phase I study, and (2) to perform a first order comparison of the improved vehicle with other system concepts in a manner which would isolate the performance and cost effects of steering technique, launch vehicle propulsion, and the spacecraft configuration.

The conclusions drawn from the results of the Phase II study are grouped according to the three major task areas: vehicle refinement and optimization, system definition, and comparative studies.

VEHICLE REFINEMENT AND OPTIMIZATION

Refinement of the vehicle concentrated on improvement of the aerodynamic representation of the vehicle and on the evaluation of spacecraft/launch vehicle compatibility. Optimization was pursued only in those areas where it was clear that major reductions would be made in vehicle size. Cost optimizations were not pursued except to indicate the direction that future studies should take. Furthermore, the scope of the study was limited to investigations of the launch vehicle and steering system.

The following conclusions are presented to indicate major study results within the scope of vehicle refinement and optimization:

1. The use of a regressive thrust-time profile in the third stage, together with an improved step throttling program for the steering engines, resulted in overall weight reduction of 900,000 lb, or 14% with reference to the vehicle defined at the end of the Phase I study.

2. Selection of the launch vehicle tail fin size for producing minimum steering control moments proved to be sensitive to fin planform shape in the transonic and supersonic regimes of the ascent trajectory.

3. Control system design requirements are state-of-the-art. Satisfactory gain and phase margins are characteristic of the techniques examined in this study. The first bending mode frequency at the most critical time in the flight (at liftoff) is slightly less than 1 cps or approximately the same as Saturn V.

4. The particular level of TNT equivalence specified for abort escape design analyses did not produce significant abort escape system weight penalties.

5. Escape from incipient first-stage motor failures on the launch pad is feasible and the spacecraft may be recovered with a normal horizontal landing at Patrick AFB.

6. Escape from incipient first-stage motor failures at the condition of maximum dynamic pressure is feasible, and the spacecraft may be recovered with a normal horizontal landing at Patrick AFB. This is true also for the case of a steering system failure.

7. Recovery from a high-altitude abort situation produces the most severe dynamic pressure and normal acceleration environment for the spacecraft. Mission ascent profiles used in these analyses for vehicle optimization, however, result in abort recovery dynamic pressures which are less than 1,200 lb/ft^2 and, in normal accelerations, less than 6 g's.

SYSTEM DEFINITION

The system definition studies were structured to produce better information on the operating characteristics of the head-end steering systen concept than was available during the Phase I study. It was desired to provide some clarification of those areas of operations exhibiting significant reductions in complexity and to provide an improved base for predicting total operation cost. The following conclusions summarize the results of this segment of the study:

1. The use of the solid-propellant launch vehicle propulsion with head-end steering will result in significant savings in launch pad occupancy times when compared to all-liquid-propulsion types employing conventional steering.

2. Transportation of the spacecraft from recovery site to refurbishment site in the Super-Guppy aircraft is feasible.

3. Primary refurbishment tasks would be accomplished at the launch site location.

4. Refurbishment analyses made for the 44-ft HL-10 spacecraft employing an all-ablative, double wall thermo-protection system resulted in costs slightly over 10% of spacecraft procurement costs per refurbishment. This cost is that required to bring the spacecraft to the same condition as a new spacecraft when received at Cape Kennedy.

COMPARISON STUDIES

The third major task area was concerned with providing a group of model systems, a comparison of whose characteristics could be used to isolate the performance and cost effects of steering technique, launch vehicle propulsion, and spacecraft configuration. The characteristics of the model systems and the types of comparisons are shown in Table 1-1.

Configuration I is the head-end steering system concept evolved in the Phase I study and refined and optimized in the Phase II study. Configuration II employs secondary liquid injection in the booster motor nozzles for steering control. Through a comparison of Configurations I and II, the effect of steering technique was isolated. Both Configurations I and II were required to perform the extended Manned Orbital Research Laboratory (MORL) mission with a direct ascent to a 300-nmi circular orbit rendezvous.

The next group of four vehicles (Configurations III, IV, V, and VI) was required to perform the Large Orbital Research Laboratory (LORL) mission with a space station rendezvous at 260 nmi, employing a Hohman transfer from a 105-nmi parking orbit. The characteristics of these vehicles were selected to enable a separate identification of performance and cost effect resulting from steering technique, launch vehicle propulsion, and spacecraft configuration and from the combined effect of all three of these characteristics.

The third group of vehicles (Configurations VII and VIII) has mission requirements which are nearly the same as for Configurations I and II. They differ, however, in that a 105-nmi parking orbit is used and they possess somewhat lower in-orbit maneuvering capability. This third group was structured to permit a comparison of an all-solid-propellant launch vehicle and a launch vehicle consisting of a solid-propellant first stage and a high-energy liquid upper stage, the S-IVB.

Table 1-1

COMPARATIVE STUDY VEHICLE DESCRIPTION

Configuration	Spacecraft Type	Booster Type	Steering Technique	Mission Description	Type of Comparison
GROUP A					
I	HL-10	Solid	HES	Extended MORL	Effect of Steering Technique (I, II)
II	HL-10	Solid	PTVC	Extended MORL	
GROUP B					
III	BALLOS	Liquid (Saturn IB)	PTVC	BALLOS-LORL	Effect of L/V Propulsion (III, IV)
IV	BALLOS	Solid	HES	BALLOS-LORL	Effect of Steering Technique (IV, V)
V	BALLOS	Solid	PTVC	BALLOS-LORL	Effect of Spacecraft (V, VI)
VI	HL-10	Solid	HES	BALLOS-LORL	
GROUP C					
VII	HL-10	Solid - First Stage Liquid - Second Stage	HES - First Stage PTVC - Second Stage	Extended MORL	Effect of Steering Technique and Upper Stage Propulsion (VII, VIII)
VIII	HL-10	Solid	HES	Extended MORL	

Figure 1-1 is presented to clarify the major system characteristics and the comparison data generated in the study. These data resulted in the following conclusions applicable to manned space vehicles performing logistics missions in low Earth orbit:

1. The performance and cost effectiveness of the head-end steering technique were found to be sensitive to the spacecraft configuration employed.

   A. Head-end steering integrated with a lifting-body type of spacecraft results in a vehicle which is more cost effective, reliable, and has quicker launch response time than a vehicle which uses conventional thrust vector control techniques.

   B. Head-end steering when used with a ballistic type of spacecraft results in a vehicle which is less cost effective and less reliable than when conventional steering techniques are employed.

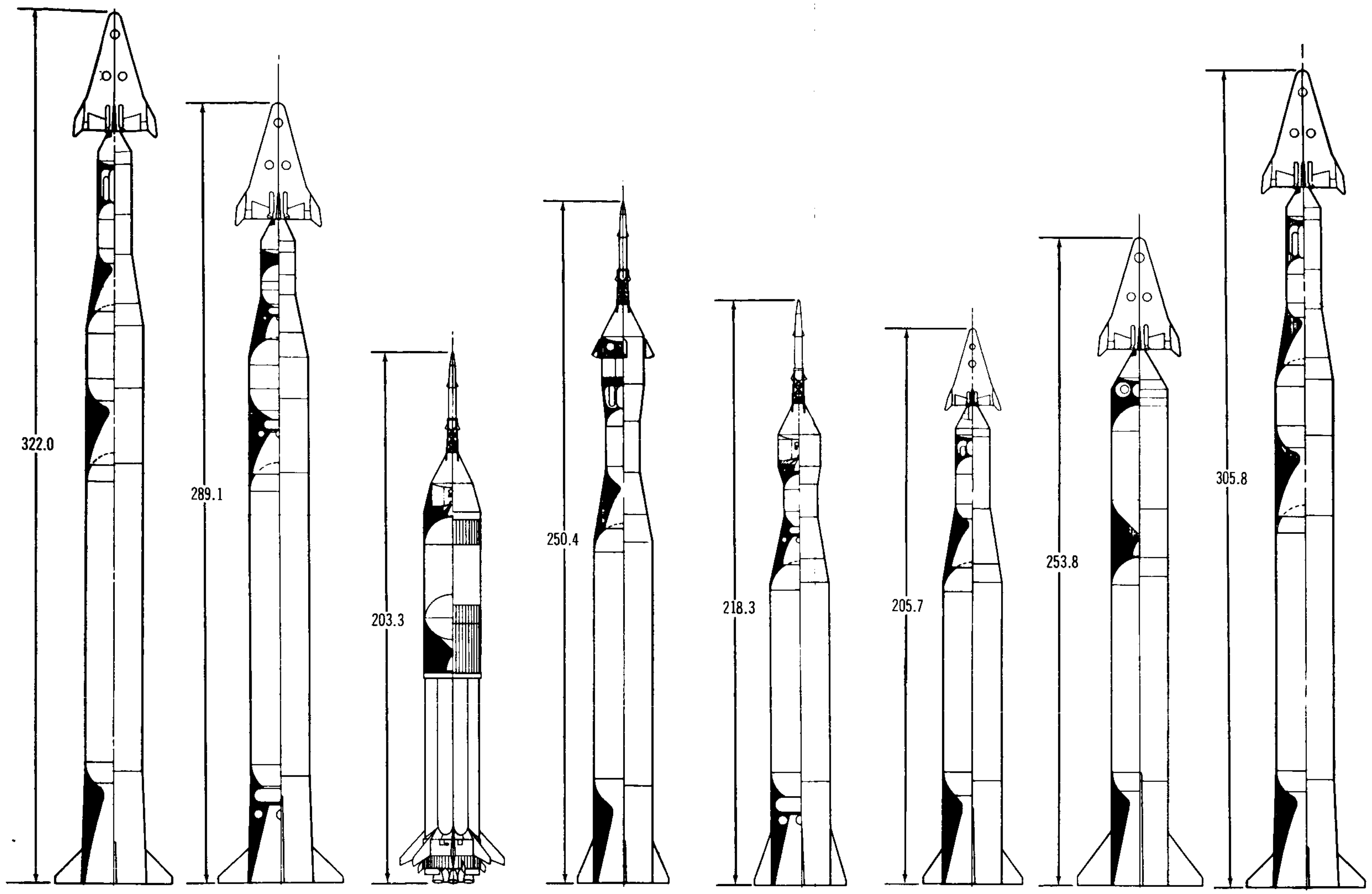
2. The use of lifting body spacecraft significantly reduces space recovery costs for missions requiring high orbit inclinations.

3. Launch vehicles employing all-solid-propellant stages are more cost effective than those employing all-liquid propulsion.

4. A high-energy liquid upper stage when used with a solid-propellant first stage results in a launch vehicle that is competitive in cost and performance with a vehicle which incorporates solid-propellant motors in all stages.

5. The combined effect of all-solid-propellant booster motors, head-end steering, and a lifting body spacecraft results in a vehicle that is twice as cost effective as one which uses all-liquid propulsion, conventional steering, and a ballistic type spacecraft.

A brief examination of all eight vehicles shown in Figure 1-1 indicates some interesting similarities. For instance, the first-stage propellant requirements for Configurations VI, VII, and VIII are nearly the same. The first-stage motor size of VI is smaller by 7.6% than that of VII. The first stage of VIII is 11.8% larger than that of VII. This suggests the incorporation of a first stage designed for the payload class of Configuration VII (96,000 lb) and used for a configuration similar to VI, with a potential payload capability somewhat in excess of 46,000 lb. Use of this same first stage for Configuration VIII is feasible, but with a small degradation in payload.



MODEL DESIGNATION	I	II	III	IV	V	VI	VII	VIII
MISSION	EXT. MORL	EXT. MORL	LORL	LORL	LORL	LORL	EXT. MORL	EXT. MORL
CARGO, MAXIMUM (LB)	37,400	37,400	13,455	13,455	13,455	13,455	37,400	37,400
NO. OF MEN, MAXIMUM	13	13	12	12	12	12	13	13
MANEUVER CAPABILITY, BASELINE (FT/SEC)	5,820	5,820	1,050	1,050	1,050	1,050	5,270	5,270
GROSS WEIGHT, LIFTOFF (LB)	5,727,830	5,294,980	1,314,650	4,111,750	3,493,300	3,423,050	3,694,790	5,216,700
NUMBER OF STAGES	3	3	2	2	2	2	2	3
LAUNCH VEHICLE PROPULSION	ALL-SOLID	ALL-SOLID	ALL-LIQUID	ALL-SOLID	ALL-SOLID	ALL-SOLID	SOLID/LIQUID	ALL-SOLID
TYPE OF STEERING	HES	LITVC	GIMBALED ENGINES	HES	LITVC	HES	HES/GIMBAL ENG.	HES
POTENTIAL RELIABILITY REL. TO VI	.986	.950	.984	.979	.984	1.000	.980	.986
FIRST FLIGHT COST	59.07/58.99	57.79/57.71	44.68/50.66	38.26/44.24	36.72/42.70	36.87/36.79	54.68/54.60	57.30/57.22
EXPENDABLE HARDWARE	17.53	18.75	20.82	14.40	12.86	10.83	13.30	15.76
SPACECRAFT	38.54	36.04	19.55	19.55	19.55	23.04	38.38	38.54
LAUNCH SUPPORT	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
RECOVERY SUPPORT *, 30°/90°	1.00/0.92	1.00/0.92	2.31/8.29	2.31/8.29	2.31/8.29	1.00/0.92	1.00/0.92	1.00/0.92
SUBSEQUENT FLIGHT COST								
(A) 30° ORBIT – 10% REFURB. COST	25.43	26.48	28.42	21.57	19.98	16.78	20.95	23.56
(B) 30° ORBIT – EST. REFURB FROM NASA INDUSTRY STUDIES	25.70	26.91	31.31	24.46	22.87	17.25	21.14	23.83
(C) 90° ORBIT – 10% REFURB. COST	25.35	26.40	34.40	27.55	25.96	16.70	20.87	23.48
(D) 90° ORBIT – EST. REFURB. FROM NASA INDUSTRY STUDIES	25.62	26.83	37.29	30.44	28.85	17.17	21.06	23.75
SUBSEQUENT FLT. COST RELATIVE VI (ORBIT – 30°/90°)	1.49/1.49	1.56/1.56	1.81/2.17	1.42/1.77	1.33/1.68	1.00/1.00	1.23/1.23	1.38/1.38

24-HR WAIT TIME

Figure 1-1. Manned Space Vehicle Comparisons

The gross second-stage weight of the S-IVB of Configuration VII (269,070 lb) and the gross third-stage weight of Configuration VIII (307,740 lb) would permit use of the S-IVB as the third stage of Configuration VIII. A significant increase in payload would result.